

(51) Int. Cl.<sup>6</sup>:  
**H 01 L 29/167**  
H 01 L 21/22  
H 01 L 21/265

(19) FEDERAL REPUBLIC OF GERMANY  
  
GERMAN PATENT AND TRADEMARK OFFICE

(12) **Patent Disclosure**

(10) **DE 197 38 512 A 1**

(21) File No.: 197 38 512.5  
(22) Date of Application: 03 September 1997  
(43) Date of Disclosure: 18 February 1999

Application disclosed in concurrence with the Claimant per Ger Pat Code § 31 Sec 2 item 1

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(56) Prior-art documents cited: EP 04 57 508 A2  
US pub: J. Appl. Phys., vol 82, July 01, 1997, pp 419-422;  
Ger pub: phys stat sol (a) vol 154, 1996, pp 197-217;  
US pub: J. Appl. Phys., vol 43, 1972, pp 3677-3682;  
US pub: Sov. Phys. Semicond., vol 11, 1977, pp 1186-1187;  
NL pub: Nuclear Instruments and Methods in Physics Research B, vol 19/20, 1987, pp 822-825.

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The following information has been taken from the documentation submitted by the claimant

Request for review per Pat Code § 44 has been submitted

(54) Diamond Layer of a Microelectronic Component, and Method for its Production  
(57) This invention relates to a diamond layer and to a method for doping the diamond layer of a semiconductor component at least in part produced by an epitaxial process, into which diamond layer at least one doping element of the IVb group of the periodic system is introduced.

## Description

This invention relates to a diamond layer of a microelectronic component per the conceptual specification in claim 1, and to a method for its production as specified in claim 6 and, respectively, in claim 11, both generically described in and based on US patent 5.278.430.

US patent 5.278.430, to which reference is made, describes a microelectronic component which includes diamond layers. These diamond layers are both p- and n-doped, with the acceptors for p-doping constituted of elements of the IIIrd main group of the periodic system while the donors for n-doping are elements of the Vth main group of the periodic system.

US 5.508.208 describes a diamond layer n-doped with lithium (Li). The doping process is assisted by a  $\text{LiN}_2$  plasma whereby the energized lithium atoms are diffused into the diamond layer.

US 5.382.809 refers to nitrogen (N), phosphorus (P), silicon (Si) and carbon (C) as doping elements.

In the case of all these traditional doping elements, their reproducibility, especially in n-doping has proved inadequate.

It is the objective of this invention to introduce a diamond layer for a microelectronic component, which permits good doping and especially n-doping with a high degree of reproducibility.

An additional objective is a method for producing the diamond layer.

These objectives are achieved by means of the characterizing features of claim 1 for the diamond layer of the component and, respectively, by the procedural steps per claim 6 and claim 11 for the production method. Doping the diamond layer, especially with titanium either by ion implantation or in situ during the growth of the diamond layer results in unambiguous semiconductive properties in the diamond layers doped in accordance with the invention.

Other practical variations of the invention are covered in the appropriate remaining claims. The invention is further explained in more detail with the aid of an implementation example illustrated in the drawings in which –

Fig. 1 is a perspective view of a structured and a Ti-doped diamond layer on an intrinsically semiconductive diamond layer;

Fig. 2 is a cross-section view of the layered structure per fig. 1 along its longitudinal axis;

Fig. 3 is an Arrhenius graph of the specific conductivity of a titanium-doped sample; and

Fig. 4 shows the doping profile of a Ti-doped sample.

Illustrated in fig. 1 is a layered structure where an intrinsically semiconductive diamond layer 2 supports a diamond layer 2 that is doped with a particular element. A cross-sectional view thereof along the longitudinal axis is shown in fig. 2. In the case of this invention, the doping element is titanium. The layered structure permits the conductivity of the doped diamond layer to be measured, for which purpose the Hall measuring method is employed. In this process, an electric voltage ( $U_{\text{Versorgung}}$ ) is applied between the two external contacts (left and right), while a magnet generates an inhomogeneous magnetic field in the structural center area of the doped diamond layer 2. For measuring the Hall voltage the magnet is placed on the unit once from the top and once from the bottom and is adjusted until a maximum Hall signal is obtained. The Hall voltage

( $U_{\text{Hall}}$ ) resulting from the charge separation of the charge carrier in the magnetic field is then collected at the two peripheral top and bottom connectors. This measurement was performed on a Ti-doped diamond layer 2. As a reference, a diamond layer p-doped with boron was measured. In both cases the magnet used was a Schallhammer Magnetsysteme model NdFeB35 with a magnetic field strength of approximately 1 tesla. Prior to the test, the tip of the magnet was pointed so as to produce an inhomogeneous magnetic field.

The measurements revealed a Hall voltage ratio of about -35 between the titanium-diamond layer and the boron-diamond layer. The corresponding current ratio was around  $10^{-4}$ . Mobility in the boron-diamond layer was  $50 \text{ cm}^2/(\text{Vs})$ , that of the titanium-diamond layer was  $1.7 \times 10^3 \text{ cm}^2/(\text{Vs})$ . For the titanium-doped diamond layer 2 these values indicate n-doping.

Fig. 3 is a diagram in which the specific electric conductivity is expressed in  $[1/(\Omega \cdot \text{cm})]$  of a sample over the reciprocal temperature in  $[1/\text{K}]$ . The sample displays the typical semiconductive properties of a doped layer. The activating energy for the conductivity of this doped diamond layer can be determined in conventional fashion from the slope of the straight line and is 0.27 eV.

For producing the sample, a growth substrate of silicon was provided with a heteroepitaxially oriented diamond layer by means of a plasma CVD process. This diamond layer was exposed to an ion beam. First, a dosage of  $6.0 \times 10^{14}$  titanium ions per  $\text{cm}^2$  was implanted at an energy level of 170 keV. This was followed by additionally implanting in the diamond layer at a dosage of  $3.5 \times 10^{14}$  titanium ions per  $\text{cm}^2$  with an ion-beam energy level of 80 keV.

In fig. 4 the dotted line illustrates the doping profile of the sample. In the diagram, the depth of the diamond layer is shown along the x-coordinate, starting from the blank surface i.e. the surface away from the growth substrate. The y-coordinate on the left shows the atomic density in atoms per  $\text{cm}^3$  while the percentage proportion of titanium in the diamond layer is shown along the y-coordinate on the right. The resultant undulating dotted-line doping profile is constituted of two individual distribution patterns expressed in solid lines. The distribution peaks are at around 380 Angstroms and 730 Angstroms, respectively. The associated atomic densities of the titanium in this case are  $1.6 \times 10^{20}$  atoms per  $\text{cm}^3$  and  $1.3 \times 10^{20}$  atoms per  $\text{cm}^3$ , respectively.

#### Patent Claims

1. Diamond layer of a microelectronic component produced at least in part by an epitaxial process and incorporating electrically semiconductive layers, a growth substrate and at least one diamond layer doped with an element of the periodic system, **characterized in that** the diamond layer (2) is doped with an element of the IVb group of the periodic system and that the diamond layer (2) is free of the carbide of the doping element or contains carbide in negligible amounts only.
2. Diamond layer as in claim 1, characterized in that the doping element is titanium (Ti) and that the diamond layer (2) is free of titanium carbide (TiC) or contains TiC in negligible amounts only.
3. Diamond layer as in claim 1, characterized in that the concentration of the doping element in the diamond layer (2) is between  $0.8 \times 10^{20}$  per  $\text{cm}^3$  and  $2.0 \times 10^{20}$  per  $\text{cm}^3$  and especially between  $1.2 \times 10^{20}$  per  $\text{cm}^3$  and  $1.6 \times 10^{20}$  per  $\text{cm}^3$ .
4. Diamond layer as in claim 1, characterized in that the growth substrate (1) consists of silicon (Si).
5. Diamond layer as in claim 1, characterized in that the growth substrate (1) consists of silicon (Si) and that the diamond layer (2) thereon is a heteroepitaxially oriented diamond layer (2).

6. Method for doping a diamond layer on a semiconductor component produced at least in part by an epitaxial process, whereby at least one doping element is introduced into the diamond layer, characterized in that the doping element selected is an element of the IVb group of the periodic system.
7. Method as in claim 6, characterized in that said element is introduced into the diamond layer (2) by ion implantation.
8. Method as in claim 6, characterized in that said element is introduced into the diamond layer (2) by ion implantation and the doping element is implanted at a dosage of between  $1 \times 10^{14}$  ions per  $\text{cm}^2$  and  $8 \times 10^{14}$  ions per  $\text{cm}^2$  and especially between  $3.5 \times 10^{14}$  ions per  $\text{cm}^2$  and  $6.0 \times 10^{14}$  ions per  $\text{cm}^2$ .
9. Method as in claim 6, characterized in that an element is introduced into the diamond layer (2) by ion implantation and that the ion beam employed has an energy level of between 50 and 200 keV and especially between 80 keV and 170 keV.
10. Method as in claim 6, characterized in that the element is introduced into the diamond layer (2) by ion implantation and that during said implantation the diamond layer (2) is heated to a temperature of between 800 and 1200°C and preferably to about 1000°C.
11. Method as in the basic concept of claim 6, characterized in that a growth substrate is used, which at least to a large extent consists of monocrystalline silicon.
12. Method as in claim 6 or 11, characterized in that it employs a diamond layer (2) heteroepitaxially oriented on silicon.
13. Method as in claim 6 or 11, characterized in that the doping element used is titanium (Ti) and that any formation of titanium carbide (TiC) in the diamond layer (2) is entirely or at least largely avoided.
14. Method as in claim 6 or 11, characterized in that the doping element is introduced into the diamond layer (2) at a concentration of between  $0.8 \times 10^{20}$  atoms per  $\text{cm}^3$  and  $2.0 \times 10^{20}$  atoms per  $\text{cm}^3$  and especially between  $1.2 \times 10^{20}$  atoms per  $\text{cm}^3$  and  $1.6 \times 10^{20}$  atoms per  $\text{cm}^3$ .

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 Attached: 2 pages with drawings  
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(in drawings:)

$U_{\text{Versorgung}}$  = Power supply

Leitfähigkeit = Conductivity

Reziproke Temperatur = reciprocal temperature